

FACILITY FORM 802

N 66-80353

(ACCESSION NUMBER)

(THRU)

34  
(PAGES)

None  
(CODE)

(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

EXPERIMENTS WITH THE  
BIOELECTRIC POTENTIALS

by

J. J. Konikoff

Prepared for presentation at the  
36th Annual Scientific Meeting  
Aerospace Medical Association  
April 28, 1965, New York, N. Y.

*Progress Is Our Most Important Product*

**GENERAL  ELECTRIC**

**RE-ENTRY SYSTEMS DEPARTMENT**

*A Department Of The Missile and Space Division*

**P. O. Box 8555 • Philadelphia, Penna. 19101**

## I. INTRODUCTION

It has been known that electrical energy is generated within the animal body. However, because of the relatively low level of power produced no practical utilization of these bioelectric potentials had been contemplated other than for diagnostic purposes, i.e. electroencephalograms, electrocradiograms, electromyograms.

Recent advances in microminaturized electronic circuitry have resulted in the application of transistors and tunnel diodes with the attendant important reduction in power requirements. Hence, the investigation of the bioelectric potentials as a possible power source for this class of electronic devices has become much more promising.

In 1962 a study of the utilization of the bioelectric potentials, as derived from anesthetized rats, was undertaken at the Space Sciences Laboratory of the General Electric Company and continued under NASA Contract NAS2-1420 (Ref. 1). This work resulted from an investigation aimed at the elucidation of the emf derived from the activity of microorganisms and was initially described by Reynolds (2).

Additional activity in this study area resulted in the investigation of electrical materials, anatomical sites, means for increasing the output and long term implants. This paper describes the results of these investigations.

## II. PREVIOUS WORK

Pinneo and Kesselman (3) have reported that they have been able to power an FM transmitter by inserting two steel electrodes into the brain of a cat. The transmitter has an energy input requirement of 0.5 microamps at 40 microwatts. Long (4) presented an intensive study of these biological energy sources: biological potentials and chemical gradients, blood pressure and flow, muscular activity and motion, and concluded that the last named might have a more immediate

application. Konikoff and Reynolds (5) extended their studies of biochemical fuel cells to the whole animal by analogous thinking. By considering the body as a container of electrolytes, numerous semipermeable membranes, and different tissues which metabolize differently, thus permitting a chemical gradient to exist, it becomes necessary to add a catalytic agent and an electron collector (electrode) to construct a "living fuel cell". To test this thesis, experiments were conducted by measuring the electrical output when two metallic electrodes were placed in the same or different anatomical loci of anesthetized rats.

Reynolds results from these preliminary experiments indicated that an appreciable emf was produced. Values ranging up to 240 mv at 480  $\mu$ a (115  $\mu$ w) were measured over short periods of time, using a stainless steel/platinum-platinum black electrode system. The platinum-platinum black (PPB) electrode was located within the abdominal cavity and the stainless steel (SS) electrode was inserted beneath the skin. Under an impedance of 10,000 ohms resulting from a specially designed oscillator, a voltage of 0.35 V to 0.40 V was obtained.

A receiver equipped with a loudspeaker picked up the signal generated by the oscillator at 500 kc and broadcast a loud, clear sound when located at a distance of approximately 25 feet from the rat and oscillator. Figure 1 from Reference 1 illustrates the rat/oscillator hook-up and shows the transmitted sine wave as presented on the oscilloscope.

The output from the bioelectric potential and applied as described above is attributed to the natural differences in oxidation-reduction potentials which exist in different parts of the anatomy and are enhanced by the use of one electrode containing Pt-black which is a well-known catalytic material.

### III. EXPERIMENTAL STUDIES

#### a. Methods

1. Initial studies were conducted on anesthetized rats weighing approximately 200 grams. Rabbits and dogs were finally used for long term implantation studies because of their larger size. These animals were anesthetized with nembutal during the surgical procedure for the implant and then permitted to recover under normal laboratory care.
2. A narrow category of materials was selected for investigation. These electrode candidates were chosen because of their biological inertness. In all, a total of about forty (40) combinations were investigated at the same time, it became necessary to select one or two materials as a "standard" inasmuch as an evaluation of anatomical loci was also of interest. To this end a high speed steel (HSS)/platinum-platinum black (PPB) electrode system was selected based upon the apparent maximum output achieved with this combination.
3. Organs such as liver, brain, and stomach were not tested because they are not considered ideal for long-term implantation of metallic electrodes. Such sites as intestine, rectum, abdominal cavity, bone, muscle, and the subcutaneous region were tested in pairs. For example, the PPB was placed in the abdominal cavity and the HSS subcutaneously.
4. To determine the interaction between the implanted electrode and the host, long-term implant studies were conducted. Experiments were made with both passive and active electrode systems. The passive electrode studies entailed the surgical implantation of representative electrode material only. The active electrode studies involved implanting an energy draining material (resistor) in parallel with the electrodes.



b. Results

1. Electrode-Electrical Characteristics

Table I presents the results of the material screening investigation as measured on an anesthetized rat. The compositions of those materials which are under trade names are shown on Table II. The experiments were standardized by two means. First, it became apparent early in the study that the abdominal region was a fortuitous choice because when coupled with a subcutaneous site, the electrode pair produced the greatest difference in potential. Also, the abdominal cavity is large enough to accommodate electrodes. The second related to the measurement of the voltage under load. It was established as standard that comparison values were to be taken at a resistance of  $10,000 \Omega$ . Thus, computations of power output could be compared with one another directly.

Several measurements shown on Table I are not the result of a  $10K \Omega$  loading. This is because the values at the standard resistance were insignificant.

Examination of the results indicate that the greatest output (with no tissue interaction) is derived from a high-speed steel-platinum/platinum black electrode combination. At a  $10K \Omega$  resistance, an output of  $29.2 \mu w$  results at a voltage of 0.54 v. Figure 2 illustrates several electrodes.

Manganese steel produced a higher output but caused adverse tissue reaction in the animal. The amalgamated materials, i.e. Ag, Hg, Pb, when coupled with PPB also resulted in substantial outputs (approximately 50-75 percent of that obtained with the HSS). However, great difficulty was experienced in the preparation of the amalgam, its formation into an electrode, and the attachment of a lead wire. Consequently, this class of materials was also eliminated.

In the following sections of this paper, it will be seen there is an inconsistency in the output measurements using the HSS and PPB electrode combination.

This led to a study to determine the cause and recommended correction. Since great care had always been exercised insofar as duplicating the physical dimensions and characteristics of the electrodes, this possible cause was eliminated. The HSS electrode was also eliminated from consideration because of its obvious stability. Therefore, the PPB containing a thin film of platinum black sandwiched between two screens of platinum gauze was subjected to examination. Preliminary results indicated that variations in the open circuit voltage resulted when different PPB electrodes were coupled with one HSS electrode.

Visual examination of the PPB indicated a variation in cleanliness and structural integrity of the platinum black. In order that a realistic evaluation be made to determine whether variations in output resulted from electrode material or from unclean or chemically spent electrodes, an experiment was conducted in which several cleansing techniques were applied to the electrode. Comparisons of the OCV resulting from new and reused but cleaned PPB electrodes demonstrated conclusively that the output variations noted previously resulted from improper cleaning. The recommended cleaning procedure consisted of bathing and storing the PPB in HCl until ready for implantation at which time the electrode is washed in distilled water.

It is interesting to note that the variation in output resulting from unclean PPB electrodes is only apparent when the electrode is removed from a test animal and then reinserted without adequate cleaning. No variations occur after implantation and the normal post operative recovery period. Consequently, it is important to understand that the variations are the result of experimental use, frequent short-term implantations resulting in the formation of a bacterial surface contamination when the electrode removed and stored in the air or water, and not because of a degradation of the catalytic activity of the platinum black.

## 2. Electrodes - Anatomical Loci

The initial site selected for the electrodes, the abdominal cavity and subcutaneous, has been demonstrated to result in the maximum output with the minimum animal discomfort and reaction. The selection was fortuitous and was based primarily on the fact that space was available abdominally. Additionally the location made for surgical neatness. However, several other sites were investigated as was the result of reversing the electrodes from their initial position and also the placement of the electrodes in a single anatomical locus. Table III presents the results of these experiments.

Of particular interest was experiment 'i' shown on Table IIIc. Figure 3 illustrates the animal shortly after the surgical procedure. After a post operative period of eight days, the voltage had dropped to a value of 0.01V. A second animal was prepared and a circuit similar to the original was implemented. After an initially high reading the voltage after 10 days again dropped drastically. Histological examination of the excised tissues following sacrifice indicated that the blood supply to the affected region was severely impaired. Consequently, this region was abandoned as a potential site for electrode implantation.

## 3. Effect of Electrode Size on Electric Output

In general it may be stated that the total output is a function of the active surface area of the electrode. To investigate this phenomenon studies were conducted on rats and rabbits using the HSS and PPB electrodes. It was found that increasing the size of the subcutaneous electrode (the HSS) and maintaining the surface area of the PPB at its original value has little or no effect on the output. However, reversing this, maintaining the HSS electrode at its original value, and increasing the size of the PPB electrode, resulted in an increase in output. Increasing the surface of the PPB or abdominal electrode only. Table IV, illustrates these data.

From these reading it was established that the effect of electrode size on output is an important one. A polarization study was made using a rabbit wherein the voltage resulting from a given load (resistance) impressed on the circuit was determined. Three values of resistance were selected, 10,000  $\Omega$ , 5000  $\Omega$ , and 1000  $\Omega$ . The results are shown on Table V and figure 4, which plots the results at a loading of 10K  $\Omega$ .

These results indicate that outputs substantially higher than previously obtained may be achieved by the simple expediency of increasing the PPB electrode surface area. A value of over 300  $\mu$ watts results from an approximately 2-inch diameter electrode. The method of increasing the electrode area is not restricted to only the physical enlargement of a single PPB electrode. The increased surface area may be obtained by assembling a number of wafers. The output value listed in Table IV at the 11.2 times increase in PPB area results from an electrode assembly using four rectangular wafers each being approximately 1 cm x 2 cm, and spaced about 2 mm apart by a 1 x 2 cm sponge. Figure 5 is a sketch illustrating this technique. Examination of the results of this geometry indicates that the output is not in line with the results obtained from single enlarged PPB electrode. The probable explanation is because of the narrow spacing between wafers. This apparently resulted in the unavailability of the total surface area to contribute to the reaction.

#### 4. Electrode Interaction with Host Animal

##### a. Passive

Electrodes of stainless steel (type 310), chromium, Ni foam, high-speed steel, and manganese steel were implanted in the subcutaneous regions of several rats. A PPB electrode was implanted in the intraperitoneal cavity of each animal. A silicon rubber (RTV) disc was also implanted in the subcutaneous region because this substance is used for potting the electrical circuitry. These metallic

materials were selected because of their performance in power production.

These electrodes were not connected to an electrical circuit. The main purpose of the experiment was to determine the effect of the material on the adjacent tissue (foreign body reactions, chemical reactions).

After 80 days, the rats were sacrificed and the immediate implant area was grossly examined for tissue abnormalities. In all cases, the electrodes were covered with healthy connective tissue. This reaction is to be expected. No gross tissue anomalies were observed.

The metallic electrodes (with the following exceptions) showed no surface corrosion. All maintained their initial clean, bright appearance. Manganese steel and Ni-foam each indicated slight surface discoloration, indicative of a reaction occurring at the surface. As a result, these materials are excluded from further consideration. The chromium had lost its brightness, altho no overt reaction could be detected. To further check this, PPB and chromium electrode couple was implanted in the abdominal cavity and subcutaneously, respectively, of a rabbit for additional verification. After 160 days the animal was sacrificed and the electrodes removed. The PPB which was sutured to the peritoneal membrane was examined and found to be completely encapsulated in mesentery which contained a good blood supply. The chromium electrode was removed with all surrounding tissue including some dermis. This electrode was also encapsulated in tissue. The electrode was excised, and it was found that the chromium was badly oxidized and flaky. The discolored area in the surrounding tissue was due to the absorption of the chromate. Based on this reaction, chromium has also been excluded.

#### b. Active

A simple circuit was assembled and used for test purposes during the long-term implants studies. This circuit consisted of two electrodes with a 10K  $\Omega$  resistance added so that a constant power drain occurred. A pair of leads,

initially platinum wire, then braided multi-stranded stainless steel cable (.018", 7 x 3), nylon coated to 0.032" diameter was attached to the circuit and brought out through the skin so that electrical measurements (voltage readings) could be made. Figure 6 is a photograph of such a circuit containing the 10K  $\Omega$  resistance, with HSS/PPB electrodes.

Experiments were conducted in rabbits and dogs. Initially, four implants were made in as many rabbits. The materials used were PPB-abdominal cavity, and HSS or chromium-subcutaneous. The circuits were constructed as described above, and voltage readings were measured at two-day intervals. These data are plotted on Figure 7. These data suggest that sufficient power is produced to power a 10K  $\Omega$  impedance transmitter for the number of days shown.

The experiments were terminated in every case because of broken leads.

This type of experiment was extended to two dogs. PPB and HSS electrodes were used, each having a 10K resistor across them in parallel to form a circuit. These circuits were potted in silicone rubber prior to implantation. In the one case the PPB was located in the abdominal cavity and the HSS subcutaneously (Test 1). In the other animal the HSS electrode was separated from the PPB electrode by the peritoneal membrane (Test 2), Figure 8. These tests were continued for a total of 62 days during which the output was measured regularly (Test 1), Figure 9. Test 2 had a total implant time of 62 days and regular measurements were made for 37 days, Figure 10. The animals were permitted the relative freedom of their respective cages after surgery.

The power output for these tests averaged about 9.6  $\mu$ w for Test 1 and 13.7  $\mu$ w for Test 2. The electrodes were examined after removal from the animals and showed only the usual fibrous coating which is expected whenever a foreign body is implanted. The coating did not appear to greatly retard the production of electric power.

Comparison of the output curves indicates that a more uniform output was derived from the animal that has the electrode positioned on either side the peritoneal membrane, Figure 8b.

Based upon these results, it appears justified in concluding that the fixing of the electrodes by means of sutures is also important in obtaining a steadier output and reducing possible animal discomfort.

One final long-term experiment was conducted using a rabbit. The purpose of this test was two-fold:

- a) Check constancy of output as a result of suturing electrodes in place
- b) Check output again as a function of electrode (PPB) area increase

To this end, a four-wafer PPB electrode as described previously was made (See Figure 5) and surgically tied to the peritoneal sheath within the peritoneal cavity. The HSS electrode was positioned between the obliquus externus and obliquus internus. A 10K resistance was connected in parallel to the electrode system, thus causing a constant power drain. The leads were brought out at the nape of the neck after being threaded through a subcutaneous tunnel. A voltage reading was taken approximately every three days. This experiment was continued for 128 days and terminated by sacrificing the animal at the convenience of the experimenter. During the trial period the rabbit was permitted the relative freedom of his cage and appeared to be completely normal following the usual post-operative recovery period (about 4 days). Figure 11 presents the measured values of volts over the trial period. As can be seen, after about 15 days, the output became quite steady and continued in this manner throughout the remainder of the test. Actual voltage fluctuations were about 0.01 volts, varying from 0.49 to 0.50. The power output under these operating conditions (.49V @ 10K $\Omega$  resistance) is computed to be 24  $\mu$ watts at .49  $\mu$ amps.

Upon termination of this experiment the electrode materials were removed and examined for surface discoloration or other anomalies which might indicate possible interaction with the host animal. No signs of such activity were noted. Gross examination of the animal tissue in the vicinity of the electrode loci also resulted in negative findings.

#### IV. APPLICATION STUDIES

##### a. Signal Transmission

Polarization data were accumulated and submitted to the electronic circuitry design personnel in order that miniaturized transmitters oscillating in the megacycle range be designed and constructed. A total of six units were received as follows: two crystal controlled, one modulated circuit, the remainder free-running. Figure 12 shows the relative size of the modulated and free-running transmitters after potting in RTV silicone rubber. These transmitters require an input of 0.17 volts to oscillate. The modulated unit requires 0.23V.

Difficulties arose as the result of shorts occurring at the electrode junction on the transmitter because the potting material would not adhere. Hence no long-term experiments were conducted.

However, externally used, the modulated transmitter performed well. An eight-hour experiment was successfully concluded wherein a surgical needle was used to pierce the skin in the sternum of a rat, over the heart, and a hard wire lead was connected between the needle and the proper connection on the transmitter. In this manner a loud, clear audible heart-beat signal was received on a commercial band ratio receiver at a wave length of 4.8 mc.



## V. CONCLUSIONS

The experiments conducted to date have firmly established the feasibility of the utilization of the bioelectric potentials as a primary energy source.

Several combinations of materials have proven to be benign with respect to interacting with the tissues found within the host animal. Of these it is concluded that the optimum electrode is one composed of an electrode made of high speed steel and the other platinum-platinum black. This system has demonstrated its capability of operating under a 10K $\Omega$  load in an unrestrained animal at an output of  $0.49V \pm .01$  for 128 days.

Should a higher output be desirable, conclusive studies have demonstrated that increasing the area of the PPB electrode results in an increased output.

It is further concluded that the peritoneum cavity appears to be the optimum anatomical locus wherein the electrodes are placed on either side of the peritoneal membrane with the PPB dorsad and the HSS ventrad.

Based on preliminary exploratory-type studies, it is further concluded that this system of implanted electrodes has the capability of powering specially designed transmitters having a modulated circuit such that a physiological parameter, i.e. heart beat, may be transmitted directly from the implanted animal to a radio receiver properly tuned to the transmitter frequency.

## VI. ACKNOWLEDGEMENT

The author wishes to acknowledge the important and vital role played by Mr. L. W. Reynolds. To Mr. F. Cosmi goes our deep appreciation for his devoted attention to detail and his invaluable technical contribution.

## VII. REFERENCES

- (1) NASA Contract No. NAS 2-1420 dated 17 May 1962 including portions of GE SSL proposal No. N-10092
- (2) Reynolds, L. W., "Utilization of Bioelectricity as Power Supply for Implanted Electronic Devices," Aerospace Med., 35, 115, Feb. 1964.
- (3) Pinneo, L. R. and Kesselman, M. L., "Tapping the Electric Power of the Nervous System for Biological Telemetry". ASTIA Document AD 209 067, May 1959.
- (4) Long, F. M., "Biological Energy as a Power Source for a Physiological Telemetry System", IRE Intl. Convention Rec., Pt. 9, 1962.
- (5) Konikoff, J. J. and Reynolds, R. W., "Results of Some Experiments in Biochemical Electricity." Proceedings of Biochemical Fuel Cell Sessions Interagency Advanced Power Group, Electrochemical Working Group, Publication PIC - BAT 209/5, Nov. 1962.

TABLE I

## Part 1

Output as a Function of Electrode Material

Electrode Material		Output under Load				
Subcutaneous	Abdominal	OCV	Resistance Ohms	V	$\mu$ a	$\mu$ w
White gold	PPb	.35	10K	.03	3.0	0.09
Molybdenum	PPb	.40	10K	.25	25.0	6.25
Bone plate	PPb	.35	10K	.22	22.0	4.84
Lead	PPb	.74	10K	.42	42.0	17.6
Antimony	PPb	.65	10K	.40	40.0	16.0
Brass	PPb	.46	10K	.23	23.0	5.25
Silver amal.	PPb	> 1.00	10K	.43	43.0	18.5
Silver	PPb	.25	1K	.06	60.0	3.6
Inconel	PPb	.33	1K	.08	80.0	6.4
Platinite	PPb	.45	1K	.08	80.0	6.4
Titanium	PPb	.27	10K	.06	6.0	0.36
Hafnium	PPb	< .35	Erratic - dropping potential			
Silver/lead amal	PPb	.83	10K	.32	32.0	10.24
Lead amal	PPb	.69	10K	.37	37.0	13.69
Hi-speed steel	PPb	.69	10K	.54	54.0	29.2
Carbon	PPb	.28	10K	.23	23.0	5
Mu-metal	PPb		1K	.33	330	110

TABLE I

## Part 2

## Output as a Function of Electrode Material

Electrode Material		Output under Load				
Subcutaneous	Abdominal	OCV	Resistance Ohms	V	$\mu$ a	$\mu$ w
Cr	Ag-amal	.40	10K	.21	21.0	4.41
Ag-amal	Cr	.30	10K	.15	15.0	2.25
Sb	Ag-amal	.34	10K	.17	17.0	2.89
Hf	Ag-amal	.43	10K	.05	5.0	0.25
Ag-amal	Hf	.40	10K	.06	6.0	0.36
Hf	None	.12	10K	-	-	-
None	Hf	.20	10K	-	-	-
Hf-Ag amal	None	.47	10K	.06	6.0	0.36
Pt-10% Rh	PPb	.30	2.4K	.12	50	6.0
Pt	PPb	.12	.5K	.01	20	.2
Pt - 10% Rh	PPB-DECO	.25	20K	.22	11	2.4
Pt	PPb-DECO	.06	20K	.02	1	.02
Pt	Pt-10% Rh	.10	4K	.01	2.5	.025

TABLE I

## Part 3

Output as a Function of Electrode Material

Electrode Material		Output under Load				
Subcutaneous	Abdominal	OCV	Resistance Ohms	V	$\mu a$	$\mu w$
Manganese steel	PPb		.5K	.34	680	231
Monel	PPb		5K	.28	56	15.7
Platinite	PPb		1K	.08	80	6.5
Brom.Hi-T alloy	PPb		1K	.07	70	4.9
Ag	PPb		1K	.06	60	3.6
PPb	Ta	.44	10K	.13	13	1.7
Ta	PPb	.42	10K	.34	34	11.6
SS 310	PPb	.26	1K	.07	65	4.2
Hastaloy	PPb	.39	10K	.10	100	10
Stainless <sup>(a)</sup>	<sup>(b)</sup> PPb-DECO	.68	.5K	.24	480	115
Stainless	PPb-DECO	.74	1K	.22	220	48
Stainless	PPb	.63	1K	.28	280	78
Nickel & Alloy <sup>(c)</sup>	PPb-DECO	.46	1.75K	.30	170	51
Stainless	PPb	.29	10K	.06	6	4
Ni Foam	PPb	.58	1K	.16	155	24
Ni Plate	PPb	.46	1K	.14	140	19.6
Ni Foam	PPb		10K	.27	22	4.8
Ni Plate	PPb		10K	.20	20	4.0
PPb	Ni Plate	.24	1K	.11	110	12

a) Artery clamp

b) G.E. Co., Direct Energy Conversion Operation, Lynn, Mass.

c) Five-cent piece

TABLE II  
Material Composition

Electrode Material	Percent Composition									
	Fe	Ni	Cr	Cu	Co	Mn	W	V	Si	C
1. Monel Metal	6.5	60.0	-	33.0	-	-				0.5
2. Manganese Steel	86.0	-	-	-	-	13.0	-	-	-	1.0
3. High-speed steel	75.0	-	6.0	-	-	-	18.0	0.3	-	0.7
4. Platinite	53.85	46.0	-	-	-	-	-	-	-	0.15
5. Bram Hi-Temp. Alloy	53.67	24.6	18.8	-	-	-	-	-	2.5	0.43
6. S.S. Bone Plate	63.67	12.0	18.5	-	-	2.0	(Mo 3-0)		0.75	.08
7. Gold (Pure)	99.99									
8. Silver (Pure)	99.99									

TABLE III a

Power Output Obtained from a Single Anatomical Locus

(Both electrodes subcutaneous)

Electrode Material	Output under Load				
	OCV	Resistance Ohms	V	$\mu a$	$\mu w$
HSS - PPb		10K	.32	32	10.6
Manganese Steel-PPb		10K	.38	38	14.4
Monel - PPb		1K	.10	100	10.0
Ni Foam - PPb	.51	5.6K	.28	60	14.0
PPb - PPb	.06	-	-	-	-
Ag - PPb	.21	2.5K	.10	40	4.0
Hastaloy - PPb	.25	9.5K	.14	15	2.1

TABLE IIIb

Power Output Obtained from a Single Anatomical Locus

(Both electrodes abdominal cavity)

Electrode Material	Output under Load				
	OCV	Resistance Ohms	V	$\mu$ a	$\mu$ w
HSS - PPb		10K	.35	35	12.2
Manganese steel - PPb		10K	.40	40	16.0
Monel - PPb		10K	.26	26	6.7
Platinite - PPb		1K	.08	80	6.5
Ag - PPb		1K	.06	60	3.6
Ag - PPb	.22	2.6K	.09	34	3.1
Ni Foam -PPb	.31	2.2K	.11	50	5.5
PPb - PPb	.24	3.8K	.19	50	9.5
Hastaloy - PPb	.30	1.9K	.14		



Power Output Vs Anatomic Loci

Animal	Electrode Material & Location	OCV	Resistance Ohms	V	Output $\mu$ a	Under Load $\mu$ w
a. Rat	PPB - Abdominal HSS - Subq.		10K			11.6
b. Rat	PPB - Subq. HSS - Abdominal		10K			1.7
c. Rabbit	PPB - Abdominal SS - Under biceps femoris	.17	10K	.02		
d. Rabbit	PPB - Abdominal HSS - Under biceps femoris	.42	10K	.24	24	5.8
e. Rat	PPB - Under superficial fascia dorsad to rectus sheath HSS - Subq.	.72	10K	.35	35	14.4
f. Rat	Same	.74	10K	.35	35	12.25
g. Rat	PPB - Subq. HSS - Under superficial fascia dorsad to rectus sheath	.73	10K	.34	34	11.56
h. Rabbit	PPB - Diaphragm HSS - Subq.	.73	10K	.36 & dropping	36	12.96
i. Rabbit	PPB - Between super fascia and latissimus dorsi HSS - Between super, fascia and dermis		10K	61. & dropping	61	37.2

TABLE IV  
Output Vs Electrode Area

Surface Area, Cm <sup>2</sup>		Approx. area Multiple PPB/HSS	Volts @ 10K	Power watts @ 10K
PPB	HSS			
1.5 (std)	2.0 (std)	1x/1x	0.54	29.1
8.3	2.0	5.5x/1x	0.64	40.96
12.0	2.0	8x/1x	0.63	39.7
16.8*	2.0	11.2x/1x	0.49	24.0
20.5	2.0	14x/1x	0.68	46.2
8.3	4.0	5.5x/2x	0.63	39.7
1.5	14.0	1x/7x	0.51	26.0

\*Multi-wafer electrode assembly

TABLE V  
Polarization Data

Electrode Surface Area Vs Output\*

Pt-Pt-B1 Surface Area Cm <sup>2</sup>	Voltage at			Amps at			Watts (Power) at		
	10K	5K	1K	10K	5K	1K	10K	5K	1K
1.5 (1x)	0.46	0.19	0.06	46	38	60	21.2	7.2	3.6
12.0 (8x)	0.70	0.65	0.46	70	130	460	49	84	211
20.5 (14x)	0.76	0.725	0.555	76	145	555	57.8	103	308

\*Against a 2.0 Cm<sup>2</sup> high-speed steel electrode implanted beneath the dermis and dorsad to the fascia; a new PPB made for this test was located between the external oblique.

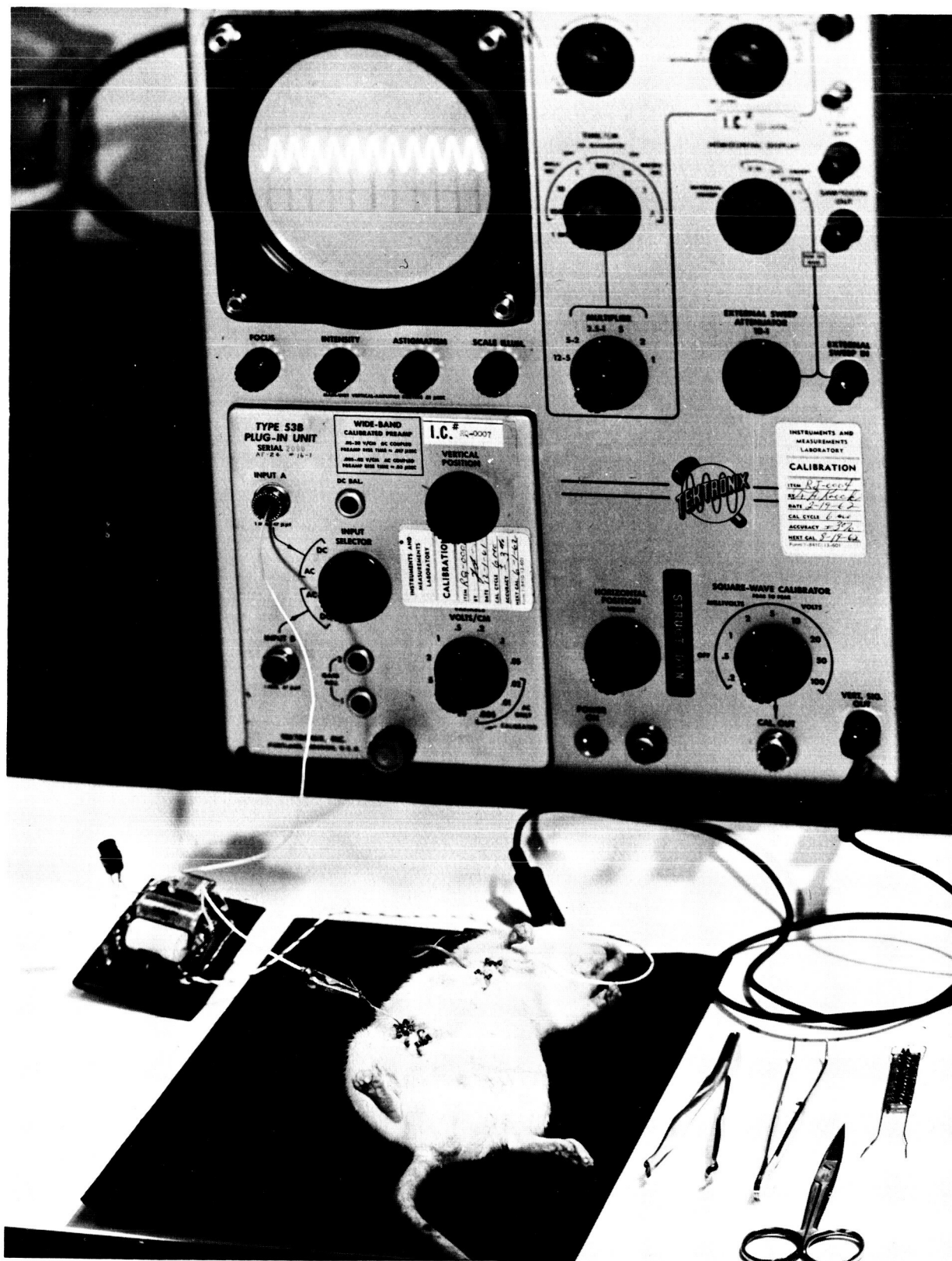


Figure 1. Early Experiment - Rat Powered Oscillator



Figure 2. Examples of Electrode Material



Figure 3. Rabbit Circuit Implantation

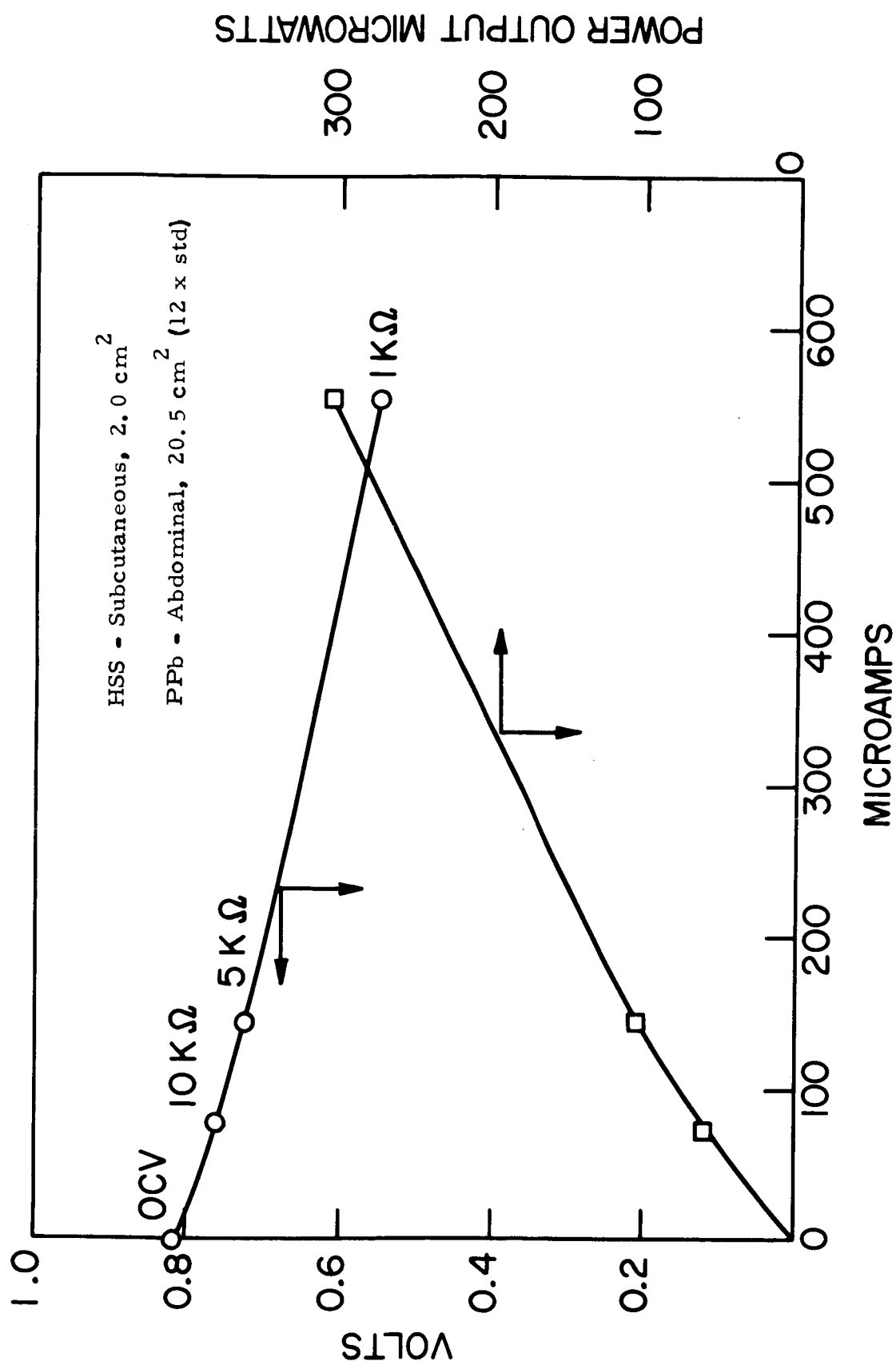


Figure 4. Polarization Curve, Extended Surface Area, PPb Electrode

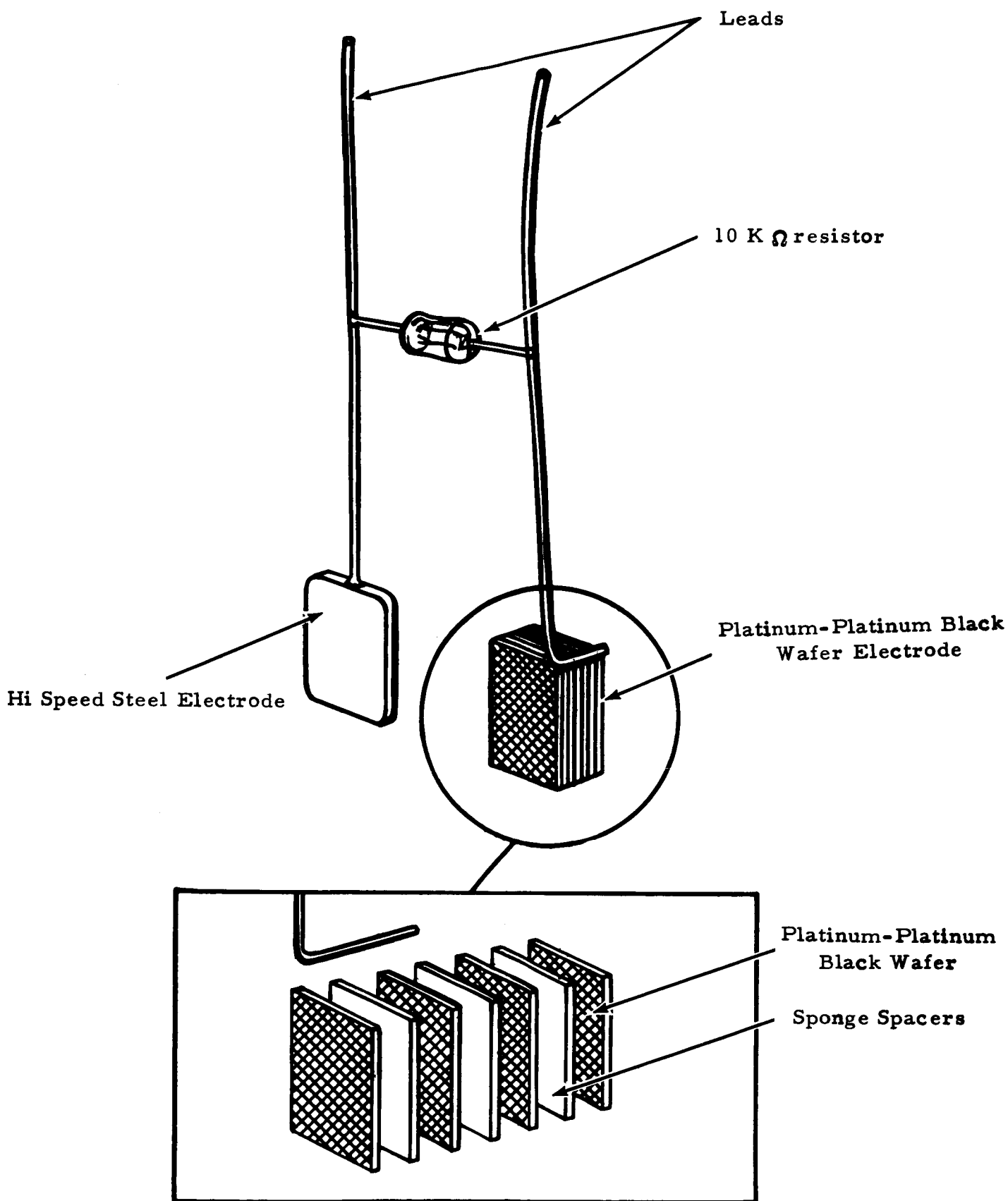


Figure 5. Sketch of Wafer PPb - HSS Circuit

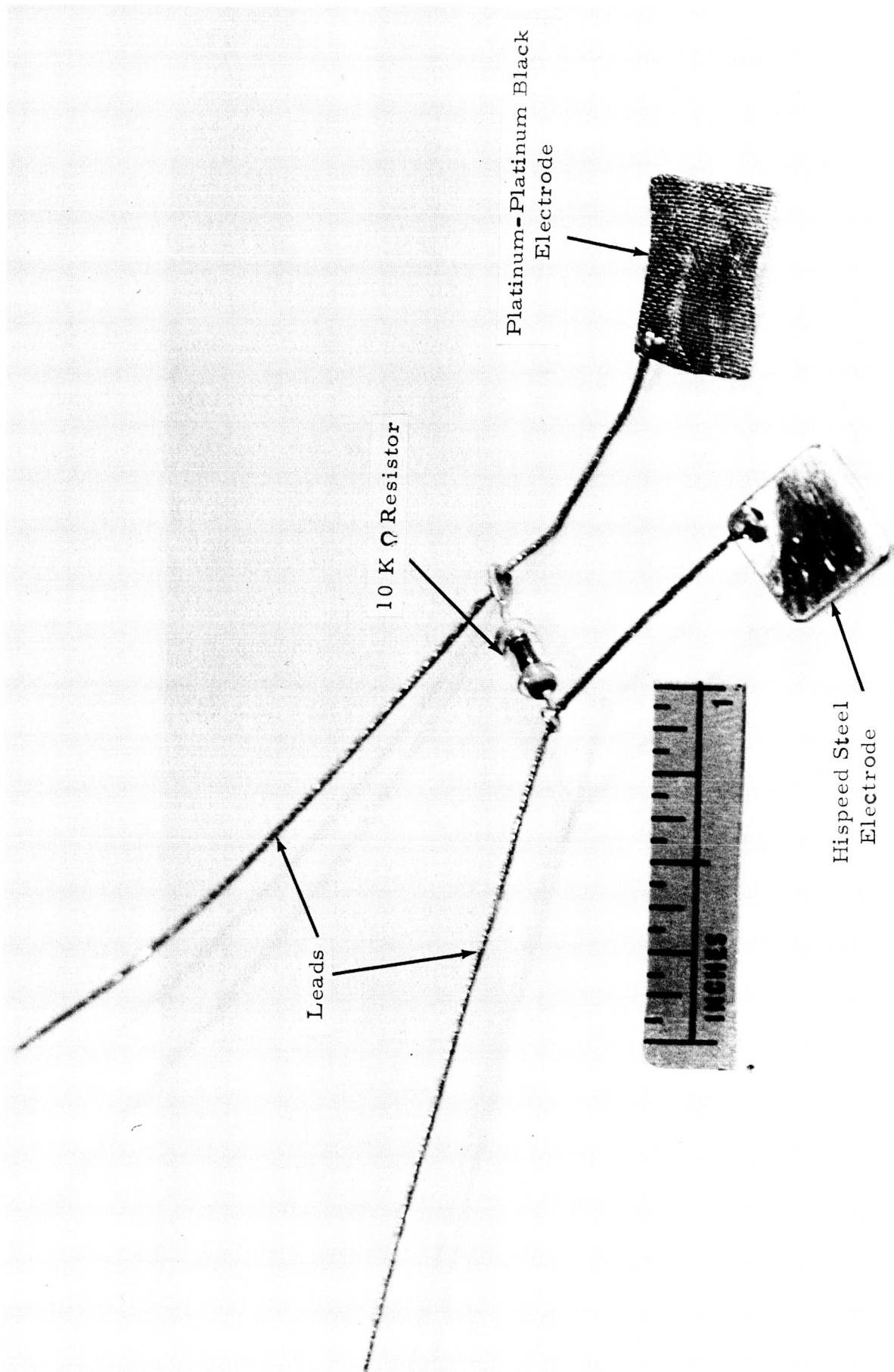


Figure 6. Circuit Used for Long-term Implant (HSS - PPb)



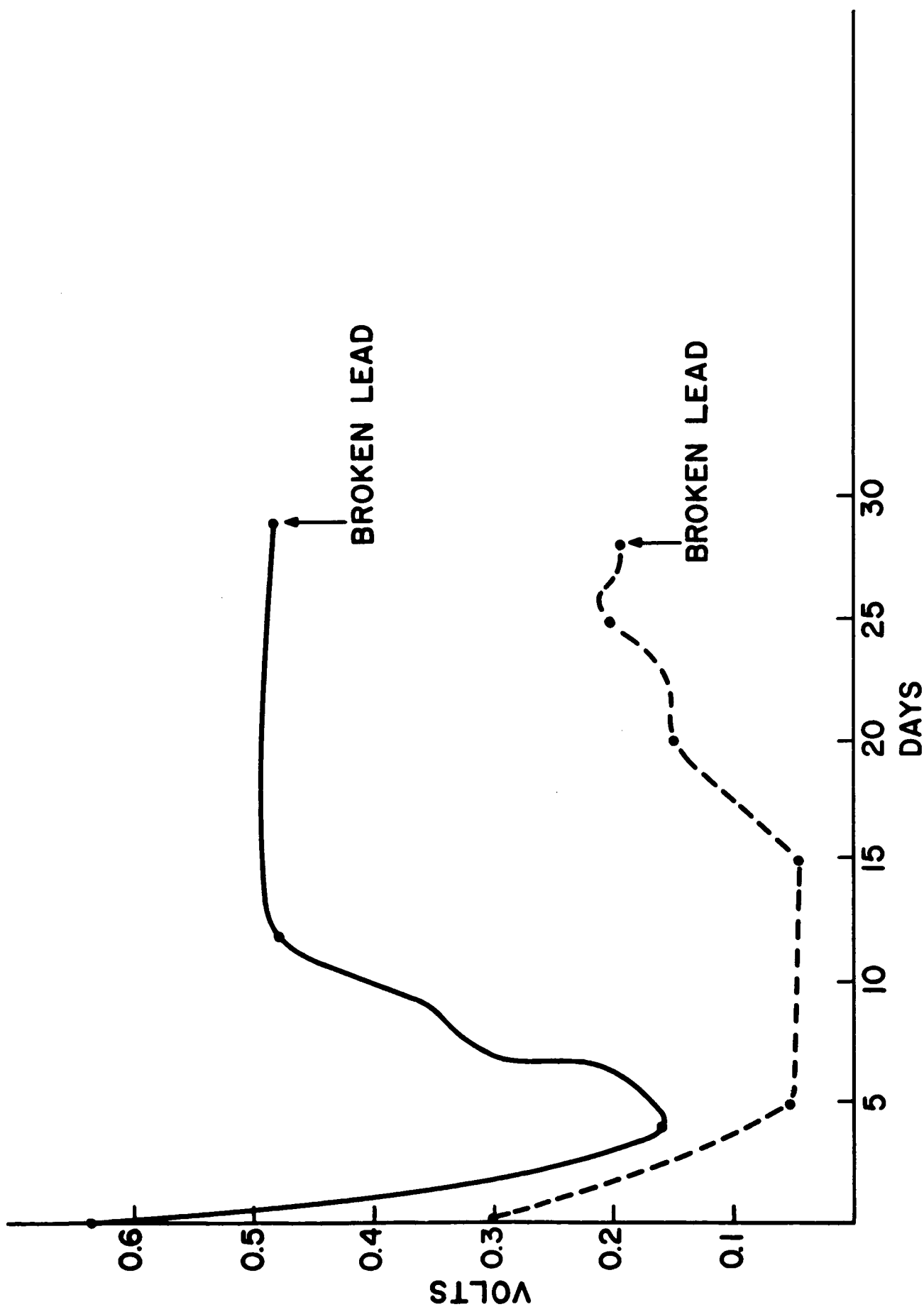
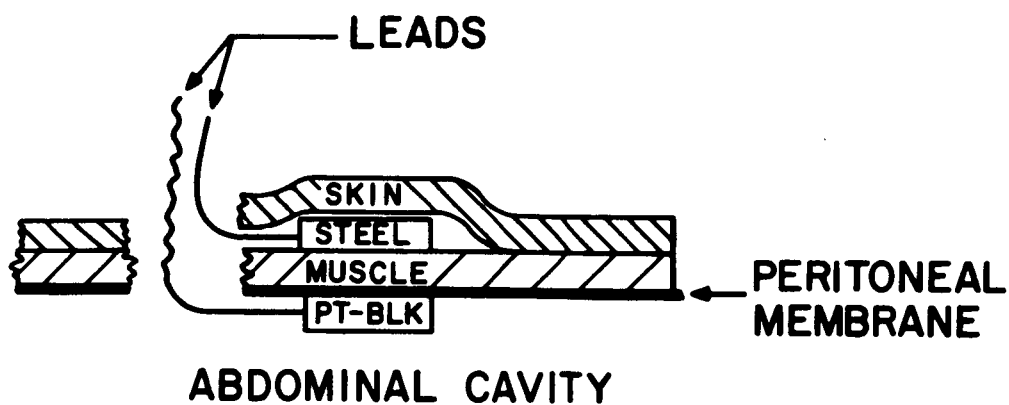
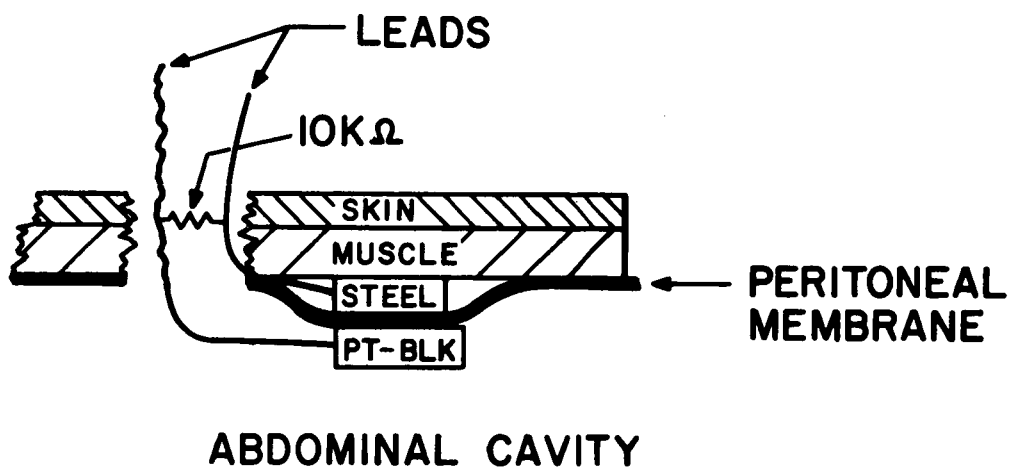


Figure 7 . Long Term Implant Study. Animal - Rabbit; Electrodes - (Pt/Pt Blk - Abdominal Cavity, Chromium - Subcutaneous); --- (Pt/Pt Blk - Abdominal Cavity, Hi Speed Steel - Subcutaneous); — ; Circuit -  $10K\Omega$  Resistance in Parallel)



**a. STANDARD LOCATION OF ELECTRODES**



**b. ELECTRODES SEPARATED BY PERITONEAL MEMBRANES**

Figure 8. Schematic Sketch Showing Electrode Positioning

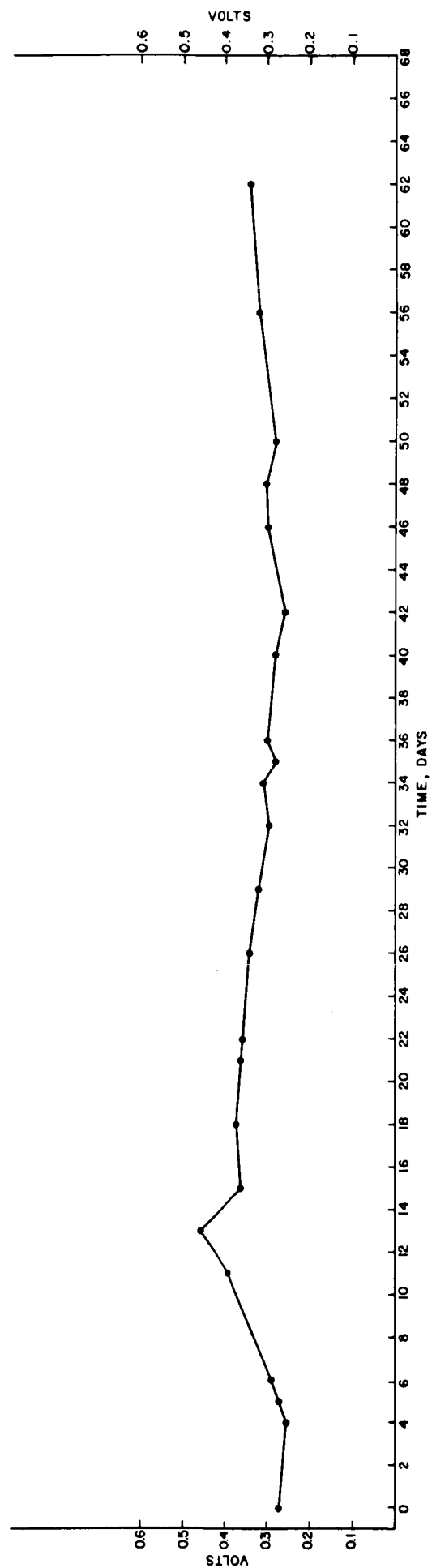


Figure 9, Long Term Implant Study. Animal - Dog; Electrodes - Pt/Pt Blk (Abdominal Cavity)  
Hi Speed Steel (Subcutaneous) ; Circuit - 10K  $\Omega$  Resistance in Parallel

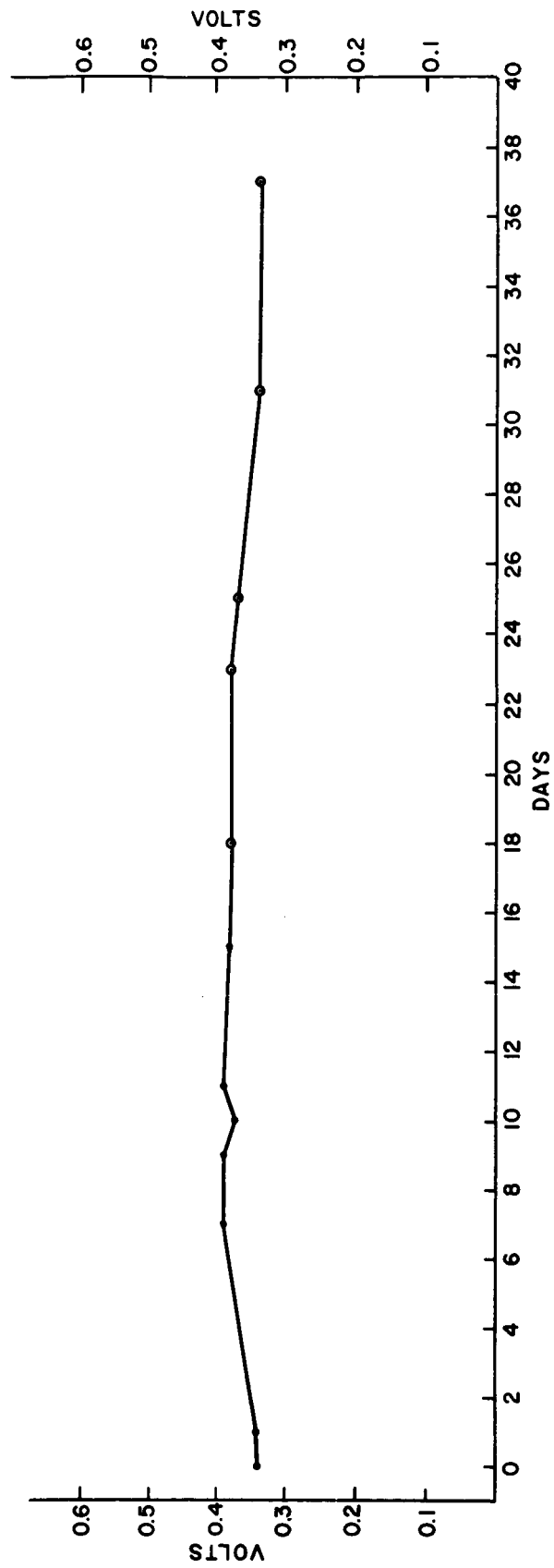


Figure 10. Long Term Implant Study; Animal - Dog; Electrodes - Pt/Pt Blk and Hi Speed Steel Separated By Peritoneal Membrane; Circuit - 10K  $\Omega$  Resistance in Parallel

Continuing Long Term Implant - Wafer Electrode

Rabbit - PPb - Peritoneal Wall - Inner  $A = 16.8 \text{ cm}^2$   
HSS - Between Obliquus Int. & Ext.  $A = 2.0 \text{ cm}^2$

$T_{\text{start}} = 5 \text{ May } 1964$

$T_{\text{end}} = 11 \text{ September } 1964$

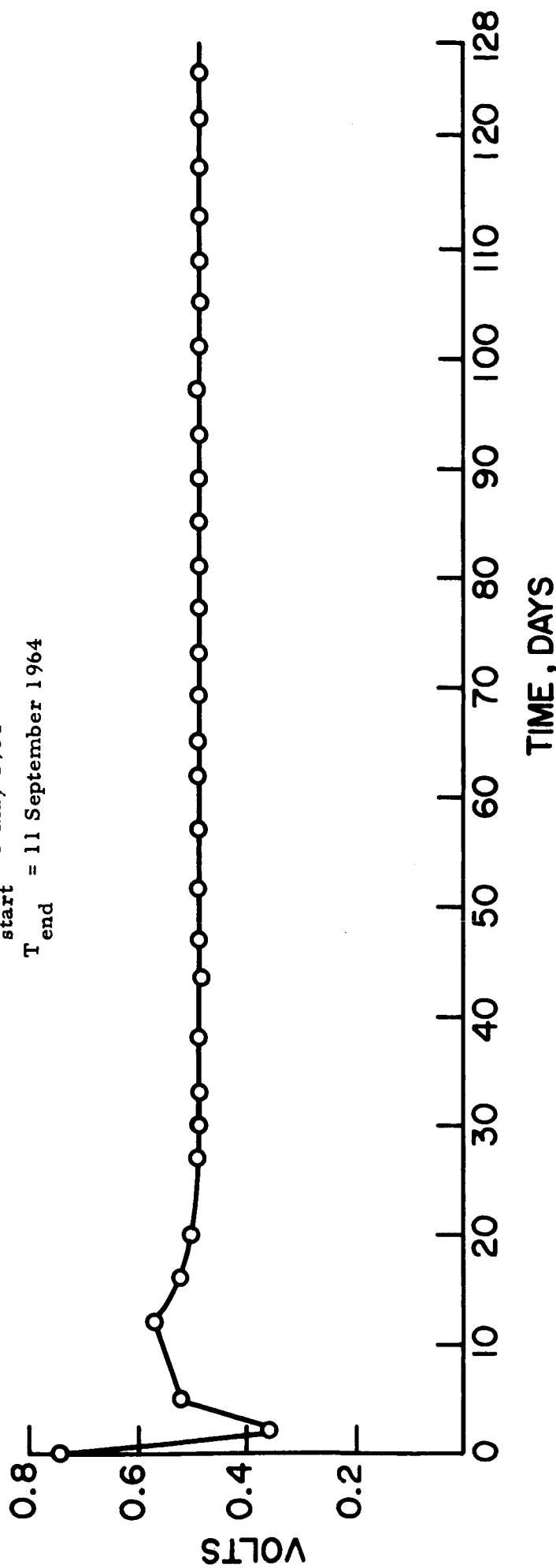


Figure 1 L Long-term Implant Study (128 days - Rabbit)

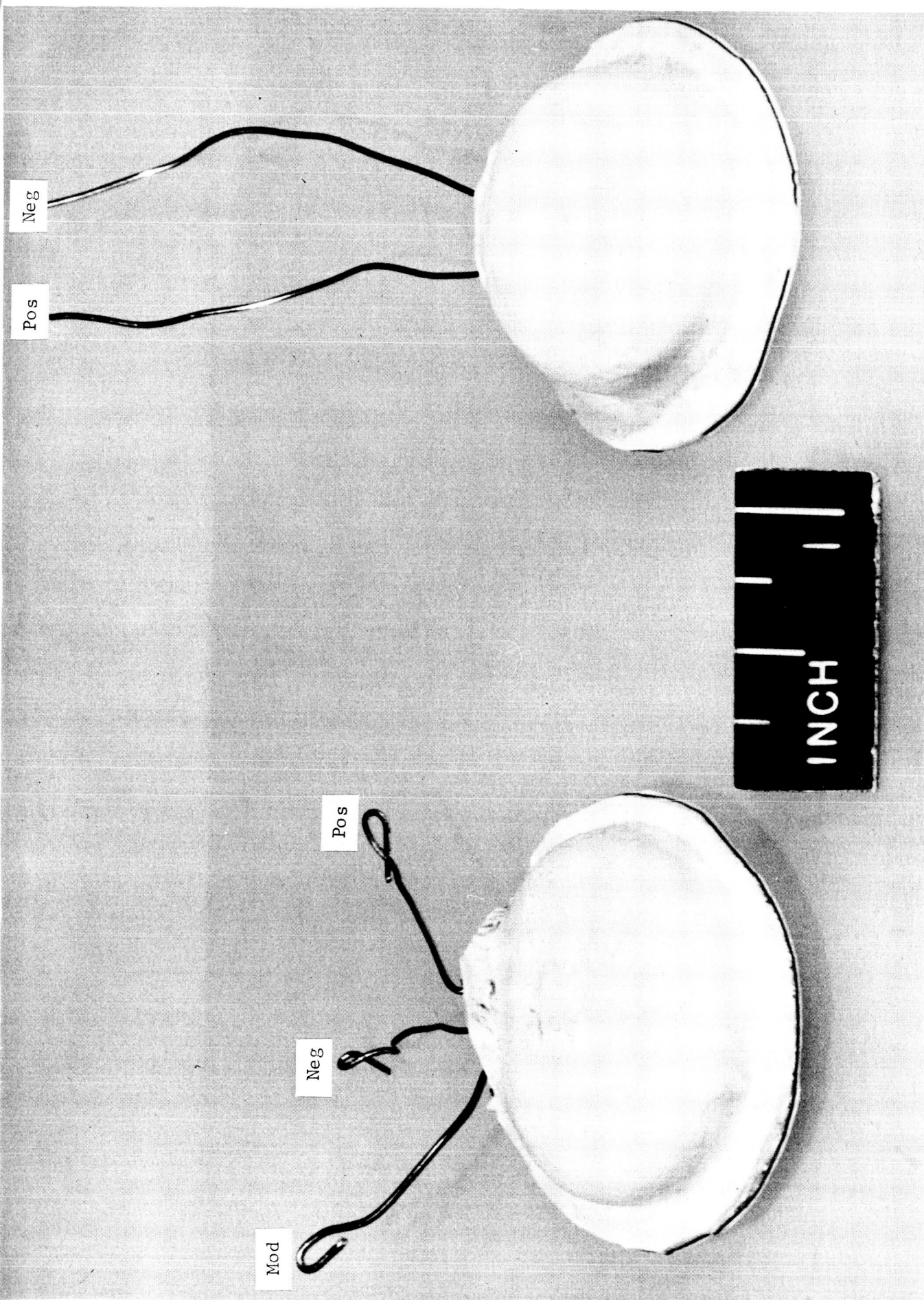


Figure 12. Modulated and Non-modulated Transmitters